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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 12/5/78

Project Title: Proposed Natural Gas Heat Pump Demonstration Project

Project No: E-25-614

Project Director: Dr. Sam V. Shelton

Sponsor: Atlanta Gas Light Company

Agreement Period: From 9/1/78 Until 2/28/79

Type Agreement: Standard Industrial Research Agreement, dated 11/2/78

Amount: $9,828 (Phase I)

Reports Required: Monthly Progress Reports; Final Report

Sponsor Contact Person (s):

Technical Matters

Mr. Tom Bradley

Contractual Matters (thru OCA)

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Defense Priority Rating: n/a

Assigned to: Mechanical Engineering (School/Laboratory)

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CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT TERMINATION

Date: 7/10/79

Project Title: Proposed Natural Gas Heat Pump Demonstration Project

Project No: E-25-614

Project Director: Dr. Sam V. Shelton

Sponsor: Atlanta Gas Light Company

TERMINATED

Effective Termination Date: 2/28/79

Clearance of Accounting Charges: 2/28/79

Grant/Contract Closeout Actions Remaining:

x Final Invoice ~~and Closing Documents~~
_ ~~Final Fiscal Report~~
_ ~~Final Report of Inventions~~
_ ~~Govt. Property Inventory & Related Certificate~~
_ ~~Classified Material Certificate~~
_ Other ____________________

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CA-4 (1/79)

E-25-614

FINAL REPORT

PROPOSED NATURAL GAS HEAT PUMP DEMONSTRATION

Prepared for
Atlanta Gas Light Company
Atlanta, Georgia

April 1979

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL ENGINEERING
ATLANTA, GEORGIA 30332

1979

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL ENGINEERING
Atlanta, Georgia 30332

FINAL REPORT

PROPOSED NATURAL GAS HEAT PUMP DEMONSTRATION

Contract E25-614

Principle Investigator
Sam V. Shelton, Ph.D.
Associate Professor

for

Atlanta Gas Light Company
223 Peachtree Street, N.E.
Atlanta, Georgia

April 1979

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL ENGINEERING
Atlanta, Georgia 30332

PROPOSED NATURAL GAS HEAT PUMP DEMONSTRATION

Sam V. Shelton, Ph.D.
Associate Professor

April 1979

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Summary

The natural gas heat pump has long offered an attractive potential for conserving natural gas for heating while simultaneously providing natural gas air conditioning. While providing air conditioning with approximately the same primary energy as electrical air conditioners, this summer gas load is advantageous to the gas utility load factor and the corresponding reduction in electrical summer air conditioning load is advantageous to the electrical utility.

The purpose of this study is three fold: (1) Determine the present technology and characteristics of natural gas heat pumps, particularly those presently being manufactured and marketed in West Germany, (2) Determine present day natural gas heat pump economic energy savings to the residential consumer compared with "conventional" heating/cooling systems, (3) Plan a project for demonstration of the Germany heat pump technology in Atlanta to determine its in-the-field operational characteristics.

The technology review found the IC engine driven units being marketed in West Germany are the only units expected to be commercially available until 1982. These residential and small commercial units have a heating COP of 1.5 with a cooling COP of 0.85.

A comparison of seven heating and cooling systems operating in a typical Atlanta, Georgia residence showed total annual utility costs as follows:

1.	Natural Gas Heat Pump	$ 678.83
2.	Diesel Heat Pump	916.92
3.	Gas Furnace/Gas A.C.	916.80
4.	Gas Furnace/Electric A.C.	954.60
5A.	Electric Heat Pump (COP_H = 1.5)	1,467.09
5B.	Electric Heat Pump (COP_H = 2.0)	1,233.10
6.	Electric Resistance Heat/Electric A.C.	1,759.64
7.	Oil Furnace/Electric A.C.	1,261.51

A demonstration program was developed to test a presently available West German heat pump in an Atlanta, Georgia residence. This program would determine field characteristics of present technology natural gas heat pumps with efficiencies approximating other concepts expected to be available after 1982.

I. Introduction

The natural gas heat pump has long offered an attractive potential for conserving natural gas for heating while simultaneously providing natural gas air conditioning. While providing air conditioning with approximately the same primary energy as electrical air conditioners, this summer gas load is advantageous to the gas utility load factor and the corresponding reduction in electrical summer air conditioning load is advantageous to the electrical utility. These benefits to the utilities will subsequently flow to the consumer in reduced energy costs.

The purpose of this study is three fold:

1. Determine present day natural gas heat pump economic energy savings to the residential consumer compared with "conventional" heating/cooling systems.
2. Determine the present technology and characteristics of natural gas heat pumps, particularly those presently being manufactured and marketed in West Germany.
3. Plan a project for demonstration of the Germany heat pump technology in Atlanta to determine its in-the-field operational characteristics.

In evaluating the economics of natural gas heat pumps, two factors must be considered. First, if a more efficient system can be utilized to perform a given task, then use of that system will result in a decrease in the amount of energy devoted to accomplishing that task. This will results inlower energy cost with the actual savings determined by the amount of energy originally used, the percentage increase in efficiency and the unit energy cost. In terms of energy use alone, any efficiency increase would be desirable, but there is the second consideration of overall system cost.

The potential energy savings of any increase in system efficiency must be compared to a number of cost factors associated with conversion to the new system. Among these factors are amortized system capital costs, incremental system maintenance cost and projected changes in energy costs during the system's useful life. If the combination of all cost increases attributable to the new system is less than the fuel savings, then installation of the new system is economically preferable to installation of a conventional system. Furthermore, if the net savings is great enough, it may even be economically feasible to replace or supplement an existing conventional system with a new system.

This study is limited to examination of the first of the foregoing considerations. That is, seven different heating/air-conditioning systems have been compared in terms of annual energy cost at current prices for a typical Atlanta residential application. The result of this comparison is a tabulation of the energy cost savings available by choosing one system over another. In evaluating a choice between any two systems, this incremental energy cost saving should be compared to the annual incremental system cost (capital amortization, maintenance, etc.) to determine the most economical system.

It should be pointed out that economics is not the only factor considered by the consumer in making his purchases. That this is the case can be readily seen by the number of electric heat pumps installed in residences to which gas is available. Many individuals are willing to buy "security" against high future utility bills by paying a capital cost premium which is not economically justified. Other psychological factors such as contributing to the nation's conservation of energy are motivating factors as well as the "enjoyment" one receives from owning a low energy consuming heating/cooling system. The sale of $20 million per year of non-economic solar collectors is one example of the results of these factors.

Although there are several natural gas heat pumps presently being investigated and/or developed in various laboratories, about one year ago manufacturers in West Germany became the first to manufacture and market natural gas heat pumps. This commercial Germany technology for small commercial and residential facilities will be reviewed and operational performance and cost presented. The status of other on-going laboratory projects will also be presented.

A demonstration project using available technology and expertise will then be presented. The purpose of this demonstration project would be to:

1. Determine in-the-field efficiency, reliability, and overall performance of presently available equipment.
2. Obtain in-the-field data for a particular natural gas heat pump which would be applicable to any natural gas heat pump presently under development. This would be the first generic type data obtained in the U.S. and show the characteristics and potential of natural gas heat pumps in general.

II. Gas Driven Heat Pump State of Technology

The concept of using a gas driven heat pump is indeed not new. Commercially available hardware to the residential consumer, however, has not been available. The only exception to this is in Germany where two small manufacturers within the past year have made units available which are applicable to residential and small commercial buildings.

A conference in Essen, Germany was held in September 1978, totally dedicated to gas driven heat pumps. This conference "Second Essen Heat Pump Conference 1978 - Drives for Heat Pumps", gave a comprehensive status report on gas heat pump technology. Abstracts of papers presented are shown in Appendix A.

Comments on papers of interest to this study are as follows:

1. Control requirements on heat pumps and their influence on the choice of drives - University of Essen

Discussion of controlling capacity of heat pumps by other than on/off control; i.e., speed variation, evaporator temperature, and condenser temperature. Speed control in conjunction with thermostatic expansion valve appears best in combination with on/off to reduce operating hours. Some storage of heat/cooling is desirable to decrease on/off cycling and total running time.

2. Drive of heat pumps by means of Diesel motors - MAN AG - Munich, Germany

Discussion of characteristics of their Diesel engines for heat pump drives (could be dual fueled):

a. Speed: 1200 - 2100 rpm variable

b. Size: 80 kw - 320 kw

c. Efficiency: 39% @ Full Load; 35% @ 50% Load; 25% @ 25% Load; Poor below 25% Load

d. Heat Pump Heating Efficiency: 1.9

e. Price: \$60/hp

f. Mean-Time-Between-Overhaul: 20,000 hours in general

Also discussed an operating heat pump installation in their Munich plant with following characteristics:

a. Speed controlled on outside temperature 1200-1750 rpm

b. 6 cylinder - 140 hp engine

c. Ground water heat source for evaporator

d. Evaporator Temperature: 35^{o}-40^{o}F

e. Condenser Temperature: 130^{o}F

They offer maintenance contracts on their engine installation.

3. Fast running four-stroke gas motors - Jenbacher Werke AG, Jenbach, Austria

This engine manufacturer said they had one of their spark ignited natural gas engines operating in Hamburg for 25 years with 120,000 hours on it. Overhaul was merely referred to as maintenance. Manufactures engines from 120 hp to 768 hp. Spark plug life of 5000 hours. Muffler life of 15,000 hours. They have a 120 hp gas engine driven heat pump in operation for 18 months in Austria.

4. Gas motors of minor performance as drive for heat pumps for domestic heating, Ford of Europe, South Ockenden, United Kingdom

They presented a very aggressive paper. They have adapted their small automotive engine to natural gas operation and are aggressively marketing it for heat pump drives. It produces 25 hp at 2000 rpm. They said several companies are designing and building heat pumps around their engine and have about five operating installations, one with close to 10,000 hours time on it. Their price is about $1000 for this complete engine.

5. Steam drives for heat pumps, Chem. Werke Huls AG, Morl

A discussion of the use of steam turbines as drives for heat pump compressors, recovering the condenser heat after the steam turbine. Large district heat applications were discussed. No planned demonstrations.

6. Heat pump system according to the absorption principle for performance feed into district heating systems - Borsig GmbH, Berlin

A presentation of a very large demonstration plant being built at Saar, West Germany, using a very large absorption machine. The heat will be produced at 210^{O}F. A coking plant will supply the heat to the absorption machine at 350^{O}F. Heat output to an industrial plant will be $10{,}000 \times 10^{6}$ Btu/hr. (3.5 megwatt). COP will be 1.46. A river will be used as the heat source.

7. Natural Gas heat pump implementations and development, G.E., King of Prussia, USA, AGA, Arlington, USA

Presentation of the Beale Free Piston Stirling engine driven heat pump. Prototype demonstration is to take place in late 1979 with field testing scheduled in 1980. Specification targets are three tons cooling capacity with a cooling COP of 0.85, and heating COP of 1.5 with a 2 to 5 year payback. Problems are starting and defrost reversing.

8. Directly-fired domestic heat pump development: Glynwed Group Services, Ltd., Solihull, U.K.

A multimillion dollar program to develop a residential gas fired heat pump exactly similar to the AGA funded Gates Rubber project seven years back. It uses a Rankine power cycle with a power turbine at

100,000 rpm driving a turbine compressor on a single shaft. The working fluid is common to both loops and is a Freon type. It is internally funded targeted for the market in early 80's. Heating COP target is 1.4 to 1.5. I personally believe this is a promising concept.

9. Small gas and diesel motor heat pumps, AWAK Apparatebau-Warmepumpen, Coburg, West Germany

This company seems to have the most highly developed presently marketable residential gas heat pump. It has either a gas engine or Diesel engine driving a reciprocating compressor with engine heat recovery. It is well packaged with sound enclosure. It produces 70,000 Btu/hr. with a heating COP of 1.5 to 2.0. Minor maintenance is required every 1,000 hours, a cylinder head teardown inspection every 5,000 hours. Overhaul is expected every 20,000 hours. They stress this is not an experimental heat pump but a commercial reality. It uses an electric motor for starting. They have built 40 units. They use an electronic control package with step speed control. Unit price is about 16,000 DM ($8,000).

10. Heating-power coupling plants - Soltron Ing., Bern, Switzerland

Discussion of an operating 150 hp diesel engine driven heat pump in Bern. It produces 400,000 Btu/hr. of heat and 60 kw of electricity. It was an installation made for its economic merits with a three year pay out. Swimming pool heating is the main load.

11. Survey in realized gas motor heat pumps in the Federal Republic of Germany, Ruhr, GA, Essen, West Germany

These people are very active in aiding people in the design and installation of heat pumps. Says economics are good for units with 500,000 Btu/hr and larger outputs. He presented results of their survey of 15 gas engine driven heat pump installations ranging in engine size from 40 hp to 350 hp. Nine were air source and six water source. Operating data was not discussed. Installations were in industrial plants, office buildings, and apartment buildings. Gas demand versus gas consumption of heat pumps compared with boilers or furnaces was discussed. They saw no problem right now but are watching it.

The performance of these units some of which are operating and some of which only exist on paper vary between a heating COP of 1.3 to 2.0 and a cooling COP of 0.8 to 1.2.

A review of these, as well as all other projects in which information could be obtained and appear to have the potential of making a commercial impact on residential heating/cooling in the next five years are as follows:

Company	Project Status	Commercially Availability Date	Concept
Glynwed Group Services Solihull, U.K.	R&D on Components	1982	Rankine/Rankine
General Electric Prussia, Pennsylvania	R&D on Components	1982	Stirling/Rankine
Floridan-Bauer Cologne, West Germany	~ 30 units in Field Operation	1978	Engine/Rankine
AWAK Coburg, West Germany	~ 30 units in Field Operation	1978	Engine/Rankine
Fiat Italy	Field Testing	?	Engine/Rankine

It appears that the gas engine driven vapor compression cycle units presently being manufactured and sold in Germany will be the only units which will be available during the next three years. Specification brochures on these two units are attached in Appendix B. These units will probably be followed by devices presently in the R&D laboratories but the date of availability, performance, and cost is only speculation.

III. Heating and Cooling System Descriptions

A. Introduction

The heating and cooling systems examined in this study fall into three basic types. The first and simplest is the direct heat source including gas and oil furnaces and electric resistance heat. These systems take an energy source, either chemical or electrical, and degrade it into heat (See Figure 1).

The heat output of these devices is one BTU per BTU of energy input for an efficiency of 100 percent or a coefficient of performance (COP) of 1.0. In the case of the furnaces some heat is lost through the flue in exhaust gas, reducing the efficiency to around 60 to 70 percent (COP = 0.6 - 0.7).

The second system type is the vapor-compression heat pump, including electric, gas and diesel heat pumps and electric air conditioners. These systems convert their energy source into mechanical work to drive a compressor. The compressor drives a thermodynamic cycle which absorbs heat from a low temperature region and "pumps" it to a high temperature region (See Figure 2).

For an air conditioner or a heat pump operating in the cooling mode, the low temperature region is the interior of the house, and the high temperature region is outside, so heat is "pumped" out of the house, cooling the interior. For a heat pump operating in the heating mode, the flow is reversed so that the low temperature region is outside, the high temperature region is inside, and heat is "pumped" into the house.

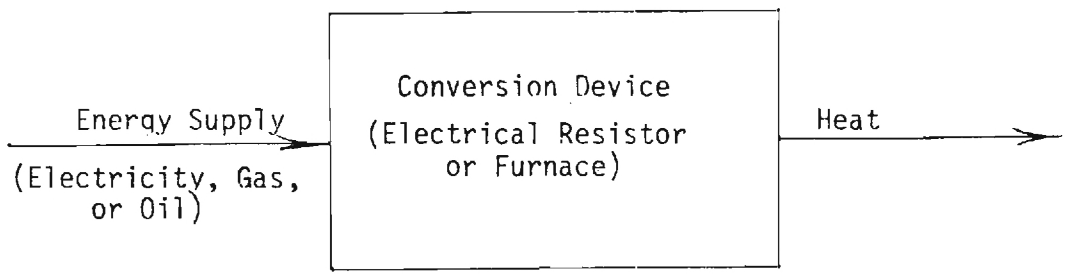


Figure 1

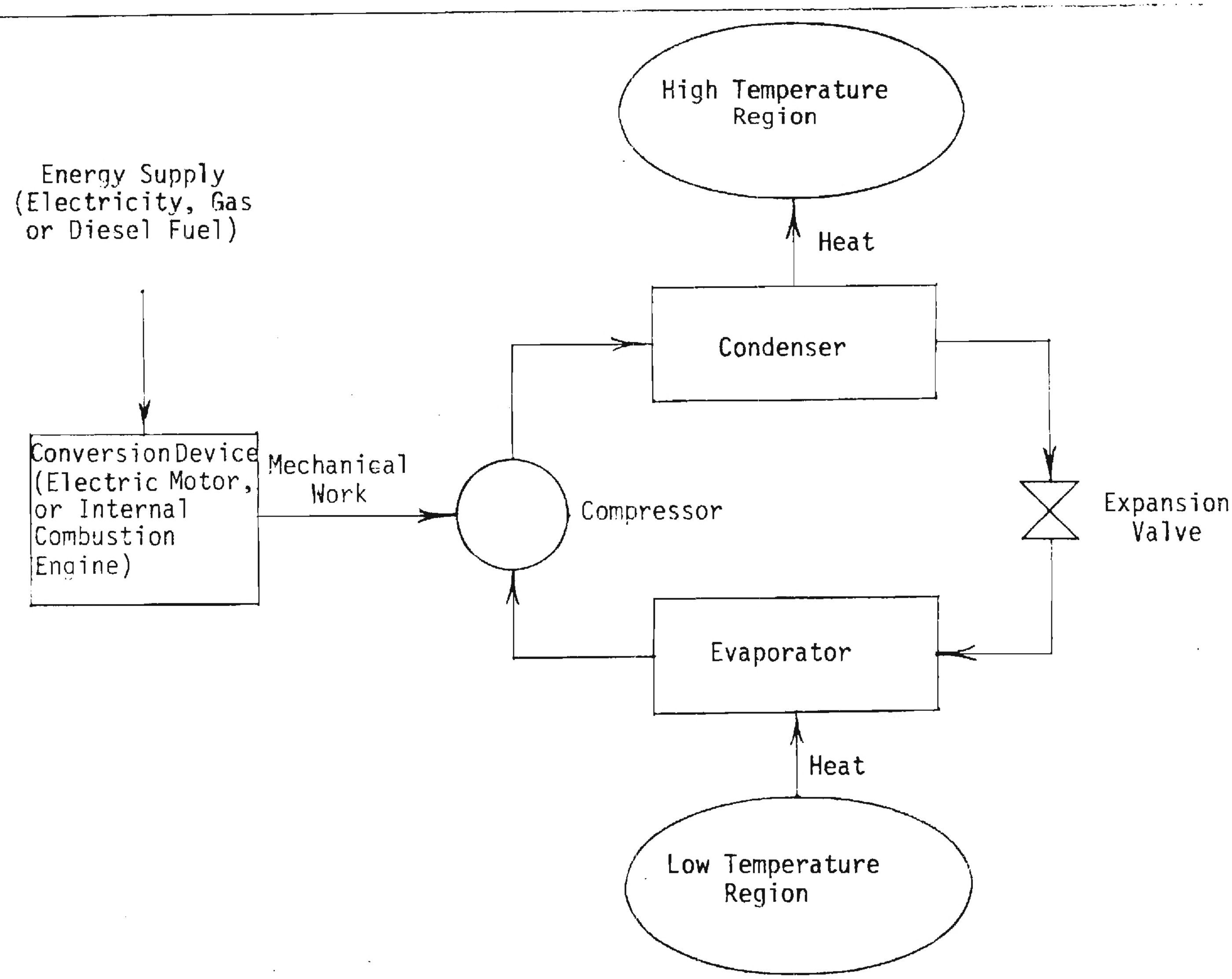


Figure 2

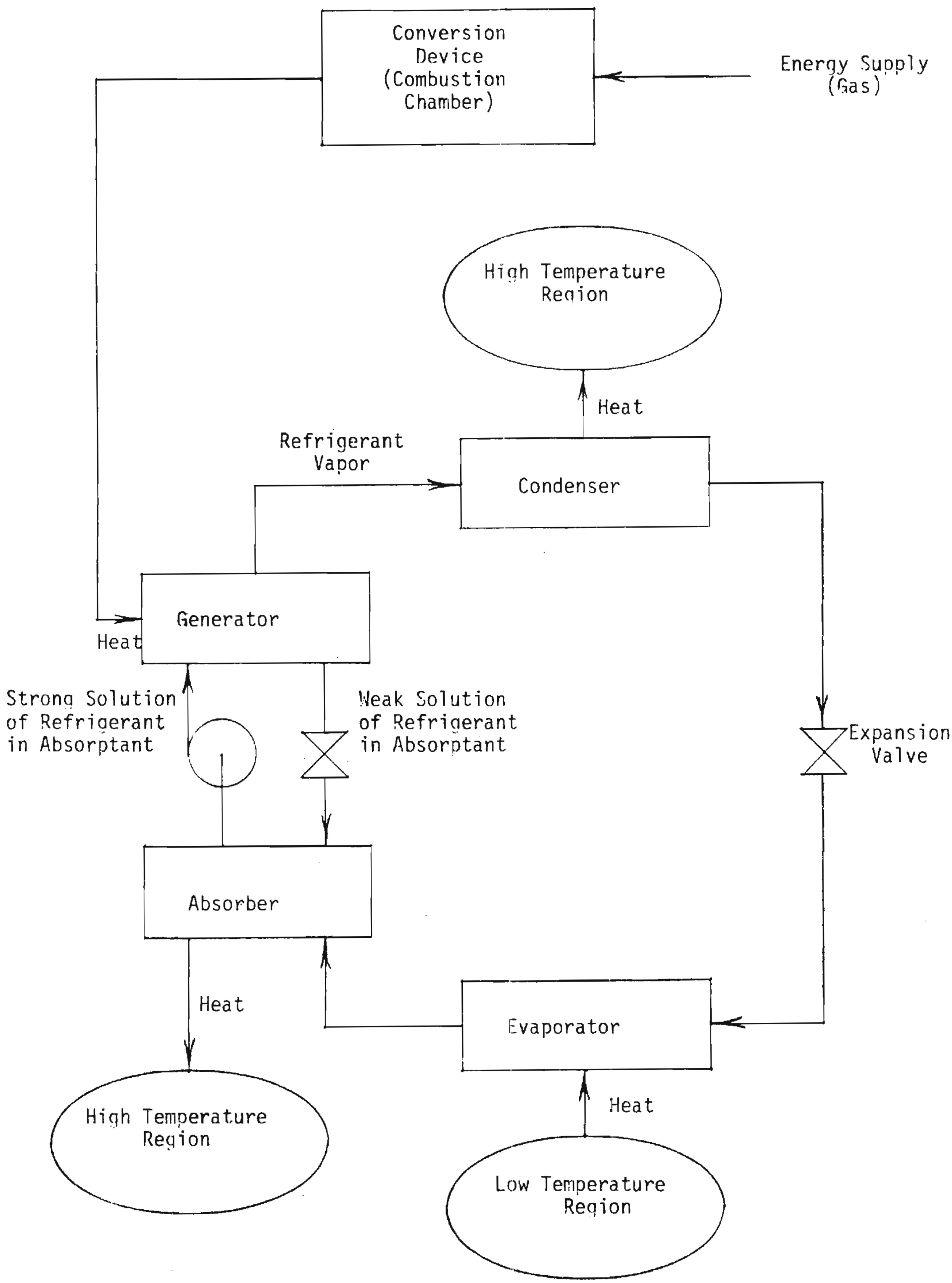
Since these heat pump systems are using their energy supplies to pump free heat which is available in the air, rather than degrading those energy supplies to heat, it is possible for them to transfer more than one BTU of heat into or out of the house for each BTU of energy used. In this way COPs greater than 1.0 can be achieved, and in fact electric air conditioners commonly operate with an average COP above 2.0. [Electric air conditioner ratings are commonly given in terms of "energy efficiency ratio" or EER. EER is the cooling output of the system in BTUs per house divided by the electrical input in watts. EER can be converted to COP by multiplying by 0.2929, thus an EER of 8.0 corresponds to a COP of 2.34, an EER of 7.5 to a COP of 2.2].

The third system type is absorption cooling, which is similar to the vapor-comparison air conditioner except that the compressor is replaced by a generator-absorber pair, and a two-component solution (absorptant and refrigerant) is used as the working fluid. The major energy intput to the system is in the form of combustion heat from natural gas, rather than mechanical work (See Figure 3).

While the same considerations concerning heat transfer versus degradation apply to both vapor-compression and absorption systems, present day absorption system typically results in COP's of less than 1.0, though in theory it can be greater than 1.0.

B. Characteristics of Systems Studied

Seven heating and air-conditioning systems are compared in this study. They are evaluated on the basis of cost to the consumer and the annual utility demand. The utility demand is of interest because



Conversion Device (Combustion Chamber)
Energy Supply (Gas)
High Temperature Region
Heat
Refrigerant Vapor
Condenser
Generator
Heat
Strong Solution of Refrigerant in Absorptant
Weak Solution of Refrigerant in Absorptant
Expansion Valve
Absorber
Heat
Evaporator
Heat
High Temperature Region
Low Temperature Region

Figure 3

currently there are peak seasons when a gas company has trouble delivering all of the required gas, and there are also times when the demand is near zero. A dampening of these fluctuations would allow the gas companies to operate on a more efficient level and therefore help keep consumer costs down.

The seven systems studied are summarized in Table 1 and are as follows:

1. Natural gas heat pump with a COP of 0.8 for cooling and 1.5 for heating. These performance figures were obtained by assuming a vapor-compression cycle COP of 2.67 driven by a gas-fired engine with a thermal efficiency of 30 percent and a 60 percent waste heat recovery in the heating mode. The Air-Conditioning and Refrigeration Institute's January-June 1978 Directory of Certified Air-Source Unitary Heat Pumps lists a number of refrigeration units which meet or exceed this COP of 2.67 assuming an electric motor efficiency of 0.83.
2. Diesel heat pump with a COP of 0.8 for cooling and a COP of 1.5 for heating. The assumptions for the diesel heat pump are the same as those for the natural gas heat pump in system 1.
3. Gas furnace for heating with 70 percent efficiency and gas absorption cooling with COP of 0.5. Atlanta Gas Light Company's field experience has shown that 0.5 is typical annual average for gas absorption air-conditioning,

Table 1. Heating/Cooling System Characteristics

	Heating		Cooling	
	Type	COP_H	Type	COP_C
1.	Natural Gas Heat Pump	1.5	Natural Gas Heat Pump	0.8
2.	Diesel Heat Pump	1.5	Diesel Heat Pump	0.8
3.	Gas Furnace	0.7	Natural Gas Absorption	0.5
4.	Gas Furnace	0.7	Electric Vapor Compression	2.3
5.	Electric Heat Pump		Electric Heat Pump	2.2
	a. Low Limit	1.5		
	b. High Limit	2.0		
6.	Resistance Furnace	1.0	Electric Vapor Compression	2.3
7.	Oil Furnace	0.6	Electric Vapor Compression	2.3

excluding air-handling equipment, for the Atlanta area. The Georgia State Energy Code currently specifies a minimum COP of 0.4 for such systems.

4. Gas furnace for heating with 70 percent efficiency and electric air-conditioning with an EER of 8.0 (COP = 2.34). The Air-Conditioning and Refrigeration Institute's January-June 1978 Directory of Certified Unitary Air-Conditioners lists residential-sized, commercially available units with EER's as high as 10.1 (COP = 2.9). Units with EER's of 8.0 are listed for a wide range of manufacturers.
5. Electric heat pump with a COP for heating of 1.5 and 2.0 and an EER of 7.5 (COP = 2.2) for cooling. The Air-Conditioning and Refrigeration Institute's January-June 1978 Directory of Certified Air-Source Unitary Heat Pumps lists a number of units which meet or exceed these criteria. An EER of 7.5 corresponds to the same vapor-compression cycle (COP = 2.67) assumed for the natural gas heat pump, driven by an electric motor with an 82.5 percent efficiency.
6. Resistance heating with a COP of 1.0 and electric air-conditioning with an EER of 8.0 (COP = 2.34).
7. Oil furnace for heating with an efficiency of 0.6 and electric air-conditioning with an EER of 8.0 (COP = 2.34).

Each of these systems represents a realistic, currently available option for residential heating and cooling. Systems 3-7 are in widespread use throughout the United States. Systems 1 and 2 are commercially available from at least two West German firms discussed in Section II but are essentially unknown here. It is the intent of this report to compare these "new" systems to the more conventional systems now in use.

IV. Atlanta Residential Energy Loads

In order to evaluate the various systems in a manner which would yield consistent and meaningful comparison, a reference load was computed for a typical Atlanta-area residential application. A 1974 study by Atlanta Gas Light Company of a typical 2000 square foot Atlanta house determined that the heating load at $18^{O}F$ was 58,900 BTU/hr. Using a base temperature of $65^{O}F$, this translates to a heat loss of 1253 BTU/hr. for each degree fahrenheit the outside temperature is below (or above) $65^{O}F$. For this study, a slightly smaller or better insulated house was assumed with a load of 1000 BTU/hr^{O}F. Using this value with 1977 Atlanta temperature data as given by the National Oceanic and Atmospheric Administration, the annual heating and cooling load for the house was determined.

The house load (q) was calculated two ways. First it was calculated on a monthly basis using the equation :

$$q = (K)\ (T)\ (T)$$

where K = 1000 BTU per HR^{O}F

t = hours in the month

T = difference between $65^{O}F$ and the average monthly temperature.

See Table 2 for tabulated results.

The second method used was the degree day method. The load in this case is :

Table 2. House Load Summary by Method 1

COOLING:	May	q =	46.6 therms	
	June	q =	108.3	
	July	q =	130.5	
	August	q =	121.2	
	September	q =	81.2	
Total Cooling:				487.8
HEATING:	October	q =	55.9	
	November	q =	99.3	
	December	q =	214.4	
	January	q =	324.8	
	February	q =	193.7	
	March	q =	93.2	
	April	q =	18.0	
Total Heating:				999.3

$$q = (K)\ (\text{Degree Days})$$

where K = 24,000 BTU per DAY F

The number of degree days was obtained from N.O.A.A. climatological data

The results are tabulated in Table 3. The difference in calculated load between the two methods was only 71.1 therms, or 4.8 percent, over the whole year. The results of method 2 were used in all subsequent calculations.

The utility load for heating and cooling is determined by the house load and the COP of the heating/cooling system according to:

$$(\text{Utility Load})_{\text{Heating and Cooling}} = (\text{House Load})/(\text{COP})$$

The monthly heating and cooling utility loads for gas, electricity and oil are shown in Tables 4, 5 and 6 respectively.

Since the total energy consumption of the house includes other factors besides space conditioning, a base load, independent of outside temperature was assumed as follows:

For hot water, range and dryer:

Gas: 37.4 therms/month

Electric: 671.3 kwhr/month

For lights and miscellaneous small appliances:

Electric: 500 kwhr/month

It was assumed that houses which used gas for either heating or air-conditioning also used gas for cooking, hot water and clothes drying.

Table 3. House Load Summary by the Degree Day Method

COOLING:	March	q = 1.7 therms	
	April	q = 13.0	
	May	q = 41.5	
	June	q = 93.9	
	July	q = 123.2	
	August	q = 116.9	
	September	q = 72.8	
	October	q = 15.3	
	November	q = 2.4	
Total Cooling:			480.7
HEATING:	September	q = 2.3	
	October	q = 42.0	
	November	q = 117.8	
	December	q = 194.7	
	January	q = 224.5	
	February	q = 179.4	
	March	q = 121.8	
	April	q = 42.2	
	May	q = 10.0	
	June	q = 0.6	
Total Heating:			935.3

The fact that the electrical heating and cooling systems include the air handler fan power requirement in their COP, while the non-electrical systems do not, require an accounting for this electrical load in the gas heating and cooling systems. The total fan energy requirements were calculated by assuming:

P_f = Fan Power Required = 365 watts/1000 cfm air (ARI Stds.)

M_a = Air Circulation Rate = 400 cfm/Ton Cooling Capacity

C_c = Cooling Capacity (Tons)

C_H = Heating Capacity (Btu/hr)

T_H = Annual Heating Time = $\dfrac{\text{Total Annual Heat Required (Btu)}}{C_H} = \dfrac{H_A}{C_H}$

T_c = Annual Cooling Time = $\dfrac{\text{Total Annual Cooling Required (Btu)}}{C_c} = \dfrac{C_A}{C_c}$

H_A = Annual Residence Heating Demand

C_A = Annual Residence Cooling Demand

Total annual fan energy required is given by:

$$(E_f)_{Cooling} = (P_f)(M_a)(C_c)(T_c) = (P_f)(M_a)(C_c)\frac{C_A}{C_c} = P_f M_a C_A$$

$$(E_f)_{Heating} = (P_f)(M_a)(C_c)(T_H) = P_f M_a C_c \frac{H_A}{C_H}$$

Assuming a heating design temperature of 20^{o}F and a cooling design temperature of 92^{o}F with a 70^{o}F base results in a heating capacity (C_H) 2.2 times the cooling capacity (C_c), i.e., with a three ton air conditioner and 80,000 Btu furnace, the total fan energy is:

$$E_f = (E_f)_C + (E_f)_H = P_f M_a C_A + \frac{P_f M_a H_A}{2.2}$$

For the Atlanta conditions taken in this study, the air handler energy requirements are then:

Cooling $(E_f)_C$ (kwhr)		Heating $(E_f)_H$ (kwhr)	
March	2.1	September	1.3
April	15.8	October	23.0
May	50.3	November	64.5
June	113.8	December	106.6
July	151.8	January	122.9
August	141.6	February	98.2
September	88.2	March	66.7
October	18.5	April	23.1
November	2.9	May	5.5
		June	0.3
Total:	585.0 kwhr	Total:	512.0 kwhr

Again it should be noted that this consumption should be added only to the gas heating and cooling systems since this A/H fan power is already incorporated in the electric system COP's.

V. Comparison of Heating/Cooling Systems

A. Energy Consumption

Given the above derived house energy requirements, the energy consumption necessary to produce these may be found. The heating and cooling system energy inputs are found by dividing the house heating and cooling loads by the system COP_H and COP_C respectively; plus, in the case of the gas and oil systems, the air handler fan power. The resulting monthly gas consumption for the gas heating and cooling systems are shown in Table 4, the monthly electrical consumption for the electric heating and cooling systems are shown in Table 5, with the oil consumption given for the oil systems in Table 6.

Combining the heating and cooling system energy requirements with the air handler (gas systems only) and the base loads yield the total monthly utility loads for each utility and each system as shown in Table 7.

B. Cost

Since the final comparison between any two systems must be economic, the total utility loads of Table 7 have been converted to annual energy costs for each system and listed in Table 8. The annual energy costs were calculated by applying the utility rate schedules included in Appendix C to the utility loads.

From Table 8 it is apparent that the natural gas heat pump not only levels out the annual gas demand but is the most economical system evaluated in terms of energy cost. The gas demand is less for this system, for both heating and air-conditioning, than it is for heating alone with a gas furnace.

Table 4. Gas Load Summary
(Heating and Cooling Only)

COOLING

	System 1 N.G.H.P.	System 3 G.A.
March	2.1 therms	3.4 therms
April	16.3	26.0
May	51.9	83.0
June	117.4	187.8
July	154.0	246.4
August	146.1	233.8
September	91.0	154.6
October	19.1	30.6
November	3.0	4.8

HEATING

	System 1 N.G.H.P.	Systems 3 and 4 G.A.
September	1.5 therms	3.3 therms
October	28.0	60.0
November	78.5	168.3
December	129.8	278.1
January	149.7	320.7
February	119.6	256.3
March	81.2	174.0
April	28.1	60.3
May	6.7	14.3
June	0.4	0.9

Table 5. Electric Load Summary (Heating and Cooling Only)

COOLING

	Systems 4,6&7 E.A.C.	System 5 E.H.P.
March	21.7 kwhr	22.7 kwhr
April	165.6	173.1
May	528.7	552.7
June	1196.2	1250.6
July	1596.4	1669.0
August	1489.2	1556.2
September	927.4	969.6
October	194.9	203.8
November	30.6	32.0
Total:	6150.7	6429.7

HEATING

	System 6 R.H.	System 5A E.H.P.(1.5)	System 5B E.H.P.(2.0)
September	67.4 kwhr	44.9 kwhr	33.7 kwhr
October	1230.6	820.4	615.3
November	3451.4	2300.9	1725.7
December	5704.5	3803.0	2852.3
January	6577.6	4385.1	3288.8
February	5256.2	3504.1	2628.1
March	3568.6	2379.0	1784.3
April	1236.4	824.3	618.2
May	293.0	195.3	146.5
June	17.6	11.7	8.8
Total:	27,403.3	18,268.7	13,701.7

Table 6. Oil Load Summary (Heating and Cooling Only)

COOLING

	System 2 D.H.P.
March	1.5 gals
April	11.3
May	36.0
June	81.6
July	107.0
August	101.5
September	63.2
October	13.3
November	2.1

HEATING

	System 2 D.H.P.	System 7 O.F.
September	1.1 gals	2.7 gals
October	19.5	48.6
November	54.5	136.4
December	90.2	225.5
January	104.0	260.0
February	83.1	207.7
March	56.4	141.0
April	19.5	48.9
May	4.6	11.6
June	0.3	0.7

Table 7. Total Residential Utility Loads

System	#1		#2		#3		#4		#5A(COP_H=1.5)		#5B(COP_H=2.0)		#6		#7	
Month	Gas	Elec	Oil	Elec	Gas	Elec	Gas	Elec	Gas	Elec	Gas	Elec	Gas	Elec	Oil	Elec
Jan	187.1	623	104.0	1294	358.1	623	358.1	623	0	5556.4	0	4460.1	0	7748.9	260.0	1294
Feb	157.0	598	83.1	1269	293.7	598	293.7	598	0	4675.4	0	3799.4	0	6427.5	207.7	1270
Mar	120.7	569	57.9	1240	214.8	569	211.4	588	0	3573.0	0	2972.6	0	4261.6	141.0	1260
Apr	81.8	539	30.8	1210	124.2	539	97.7	689	0	2168.7	0	1919.4	0	2573.3	48.9	1360
May	96.0	556	40.6	1227	134.7	556	51.7	1034	0	1919.3	0	1732.5	0	1993.0	11.6	1705
Jun	155.2	614	81.9	1285	226.1	614	38.2	1697	0	2433.6	0	2118.0	0	2385.1	0.7	2368
Jul	191.4	652	107.0	1323	283.8	652	37.4	2096	0	2840.3	0	2423.1	0	2767.7	0	2768
Aug	189.5	642	101.5	1313	271.2	642	37.4	1989	0	2728.2	0	2339.8	0	2660.5	0	2661
Sep	129.9	590	64.3	1261	186.3	590	40.7	1429	0	2174.6	0	1923.8	0	2166.1	2.7	2100
Oct	84.5	542	32.8	1213	128.0	542	97.4	718	0	2195.6	0	1939.5	0	2596.8	48.6	1389
Nov	118.9	567	56.5	1238	210.5	567	205.7	595	0	3504.2	0	2921.0	0	4653.3	136.4	1266
Dec	167.2	607	90.2	1278	315.5	607	315.5	607	0	4974.3	0	4023.6	0	6875.8	225.5	1279
Total:	1679.2	7099	850.7	15151	2746.9	7099	1784.9	12663	0	38743.5	0	32572.0	0	47609.6	1082.7	20720

G = Gas in therms
E = Electric in kwhr
O = Oil in gals

Table 8. Total Residential Consumer Costs

System	#1		#2		#3		#4		#5A (COP$_H$=1.5)		#5B (COP$_H$=2.0)		#6		#7	
Month	Gas	Elec	Oil	Elec	Gas	Elec	Gas	Elec	Gas	Elec	Gas	Elec	Gas	Elec	Oil	Elec
Jan	$ 45.74	$ 24.05	$ 41.60	$ 47.28	$ 84.04	$ 24.05	$ 84.04	$ 23.26	0	$196.74	0	$158.09	0	$274.03	$104.00	$ 46.49
Feb	38.77	23.01	33.24	46.24	70.45	23.01	70.45	22.39	0	165.68	0	134.80	0	227.45	83.08	45.62
Mar	30.35	21.80	23.16	45.03	52.16	21.80	51.38	21.98	0	126.82	0	105.66	0	151.09	56.40	45.27
Apr	21.33	20.55	12.32	43.78	31.16	20.55	25.02	25.14	0	77.32	0	68.53	0	91.58	19.56	48.80
May	23.56	21.26	16.24	44.49	31.65	21.26	14.35	37.32	0	68.52	0	61.94	0	71.12	4.64	60.98
Jun	35.93	23.68	32.76	53.16	50.73	23.68	11.22	73.23	0	108.06	0	93.14	0	105.77	0.28	104.95
Jul	43.48	25.26	42.80	54.74	62.77	25.26	11.04	92.12	0	127.27	0	107.56	0	123.84	0	123.84
Aug	43.09	24.84	40.60	54.32	60.14	24.84	11.04	87.06	0	121.98	0	103.63	0	118.78	0	118.78
Sep	30.64	22.68	25.72	52.16	42.42	22.68	11.80	60.56	0	95.82	0	83.97	0	95.42	1.08	92.28
Oct	21.96	20.68	13.12	43.91	32.04	20.68	24.95	26.17	0	78.26	0	69.24	0	92.41	19.44	49.84
Nov	29.93	21.72	22.60	44.95	51.17	21.72	50.05	22.19	0	124.40	0	103.84	0	164.90	54.56	45.50
Dec	41.13	23.39	36.08	46.62	75.15	23.39	75.15	22.69	0	176.22	0	142.70	0	243.25	90.20	45.92
				15.69												
Sub Totals	$405.91	$272.92	$340.24	$576.68	$643.88	$272.92	$440.49	$514.11	0	$1467.09	0	$1233.10	0	$1759.64	$433.24	$828.27
Totals	$678.83		$916.92		$916.80		$954.60		$1467.09		$1233.10		$1759.64		$1261.51	

From Table 8, the total annual energy costs of the evaluated systems are:

1.	Natural Gas Heat Pump	$ 678.83
2.	Diesel Heat Pump	916.92
3.	Gas Furnace/Gas A.C.	916.80
4.	Gas Furnace/Electric A.C.	954.60
5A.	Electric Heat Pump (COP_H = 1.5)	1,467.09
5B.	Electric Heat Pump (COP_H = 2.0)	1,233.10
6.	Electric Resistance Heat/Electric A.C.	1,759.64
7.	Oil Furnace/Electric A.C.	1,261.51

The natural gas heat pump shows the lowest annual energy cost of the study ($678.83). The next lowest energy cost is that of system 3, the gas furnace and gas absorption air-conditioner ($916.92), so the Natural Gas Heat Pump will save roughly $240 per year in energy costs over the cheapest alternative evaluated. Future energy cost increases will increase this savings and houses larger than 2000 ft^2 will have higher savings.

For a complete evaluation, the total annual cost of each system including amortized capital costs and maintenance costs would be required. However, if system 1 can be purchased and maintained for less than $240 per year, it would clearly be the optimum system regardless of the additional annual costs of the other systems (at current energy prices).

The AWAK-GmbH natural gas heat pump previously cited is estimated by the manufacturer to have a useful life of 15 to 20 years, with minor maintenance required annually and major maintenance at five-year intervals. Such a schedule might well be achievable for less than the

$240 annual figure. If so, only system cost would remain as a potentially prohibitive factor.

VI. Natural Gas Heat Pump Demonstration

A. Introduction

The opportunity is now available to carry out a field demonstration of the first commercially available natural gas heat pump system. This is the West Germany system using a Ford engine.

The usefulness of this demonstration would be threefold:

1. Demonstrate to the general public that more efficient natural gas heating and cooling systems are possible.
2. Evaluate, for the first time, field performance of a natural gas heat/cooling system with char-cteristics the same as future natural gas heat pumps.
3. Determine the reliability, maintenance and efficiency of currently available natural gas heat pumps.

The demonstration would be of a 5 ton size unit in an Atlanta residence to be selected. It would be instrumented to provide desired performance data over one heating and one cooling season.

B. Demonstration System

The system described herein has been selected for the purpose of supplying the heating and cooling requirements of a typical single family residence. Design of the system is such that the only energy supply required for system operation is natural gas. System controls have not been specified, but use of an electrically operated control system need not preclude manual operation of the system in the event of power failure.

The core of the heating/cooling system is an AWAK-GmbH model 18G air-to-water heat pump, driven by a natural gas fired internal combustion engine. This unit has a nominal rating of 21 kw (72,000 BTUH) for heating and 12.3 kw (42,000 BTUH) for cooling. Nominal gas consumption is 14.7 kw (50,000 BTUH) for COP's of 1.43 and 0.84 respectively.

Heat is supplied to or removed from the heat pump by a circulating water-glycol loop. Circulation is accomplished by a DeLaval/IMO model A3DB-118 pump driven by the same engine which drives the heat pump. Pump output of 50% water-glycol is 16 gpm at 100 psi with a power requirement of 1.9 horsepower. The high pressure and power requirements are the result of the water loop being used to drive the air handler fan through a hydraulic motor. Assuming a 30% engine efficiency, and 60% waste heat recovery in the heating mode, use of this pump-motor system increases gas consumption 32% and decreases COP's to 1.24 (heating) and 0.64 (cooling). Annual incremental gas cost is approximately $65/yr, partially offset by an electrical cost saving of $48/yr.

Heat is transferred between the house air and circulating water by a Magic-Aire Model HWBC-5-UL blower-coil unit with an air flow rate of 1500 cfm. At the stated air and water flow rates, this coil will transfer the nominal heat pump output to air at 80^{O}F (cooling mode) and 70^{O}F (heating mode) at 40% relative humidity with entering water temperatures of 47^{O}F and 120^{O}F respectively. The HWBC-5-UL coil with a 0.5" SP external airflow resistance requires blower power of 0.37 hp (@ 840 rpm). The blower is driven by a De Laval/IMO model A3DB-106 hydraulic motor with a power output of 0.4 hp at 16 gpm, 100 psi on 50% water-glycol.

A summary of system components and operating conditions is shown in Table 9.

Table 9. Heat Pump System Specifications

1. Heat Pump: AWAK-GmbH model 18G

A/H Drive	Gas Consumption	Cooling Capacity/COP	Heating Capacity/COP	Circ. Water	Hot Water Temperature
Electric	50,000 BTUH	42,000 BTUH/0.84	72,000 BTUH/1.43	8 gpm	113°F
Hydraulic Motor	66,000 BTUH	42,000 BTUH/0.64	81,600 BTUH/1.24	16 gpm	115°F

2. Hydraulic Motor/Pump: DeLaval-IMO models A3DB 106/A3DB 118

Fluid	Flow Rate	Pressure	Pump Power	Fan Motor Power	H
50% water-glycol	16 gpm	100 psi	1.9 hp	0.4 hp	22%

3. Air Handler: Magic-Aire model HWBC-5-UL

Water Flow	Air Flow	Inlet Water Temperature Heating	Inlet Water Temperature Cooling	H	C	ΔT_W H	ΔT_W C
16 gpm	1500 CFM	120°F	46°F	72,000 BTUH	42,000 BTUH	10°F	5.5°F

Inlet Air Temperature (40% RH) Heating	Inlet Air Temperature (40% RH) Cooling	ΔT_A (D.B.) Heating	ΔT_A (D.B.) Cooling
70	80	40°F	24°F

C. Installation

Because of the unconventional nature of the demonstration system, installation should be done by contractor with considerable technological expertise as well as experience in the commercial HVAC field. At the suggestion of Atlanta Gas Light Company, installation can be accomplished by:

Clayco Heating and Air Conditioning Company
615 North Log Cabin Drive
Smyrna, Georgia

D. Instrumentation

In order to obtain as much information as possible from the demonstration program, complete instrumentation is highly recommended. Monitoring of the natural gas input to the heat pump engine can be accomplished by a conventional demand type gas meter. This meter should be in addition to the regular house meter, and should record only the gas supplied to the heat pump itself.

The output of the heat pump can be monitored by installation of a BTU meter in the water/glycol loop. This meter should be coupled with recorders for total BTU output over a test period, and for BTU/hr output at intervals during the test period. A Conserdyne, Inc. Model JR201 BTU meter or its equivalent is recommended for this purpose.

Records should be kept of system run time, number of system starts, and indoor and outdoor temperatures. An Amprobe Instrument Inc. model LT8200R temperature/event recorder can consolidate these readings on a single chart by recording two temperature traces and a start/stop trace.

In addition to the temperature/event recorder, it may be convenient to have a separate record of total system run time, rather than calculating run time from the event record. In this case a commercially available hour-meter may be used.

In order to monitor operating conditions in the water/glycol loop, measurement of hot side temperature, cold side temperature and flow rate will be required. The temperature measurements can be accomplished with a second Amprobe LT8200R recorder, while flow rate measurement can be made with a Fisher-Porter model 3565184 rotameter.

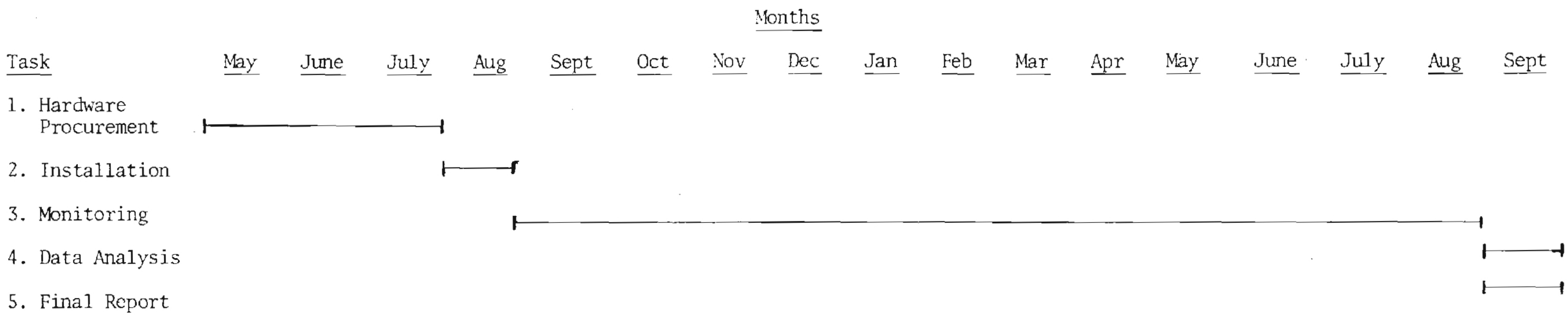
E. Maintenance and Monitoring

Any major maintenance required by the demonstration system will be done by the system installer, Clayco Heating and Air-Conditioning Company. Minor maintenance not requiring an HVAC contractor can be done by Georgia Tech personnel in conjunction with the system monitoring program.

System monitoring will be done on a weekly basis. Data collection, data reduction, formulation of program results and preparation of project reports will be accomplished by Georgia Tech personnel.

F. Schedule

Natural Gas Heat Pump Demonstration



Appendix A

Papers Abstracts

"Second Essen Heat Pump Conference 1978
Drives for Heat Pumps"

Haus der Technik e.V.

Förderungsgemeinschaft Klima e.V.

Deutscher Kälte- und Klimatechnischer Verein e.V.

2nd ESSEN HEAT PUMPS CONFERENCE 1978

DRIVES FOR HEAT PUMPS

Fundamentals, Application, Operation, Economy, Development Trends and Field Experience in Europe and USA

September 6 and 7, 1978, Essen, Haus der Technik

Technology and application of the Heat Pump have experienced a frenzied impetus and found a variety of service possibilities and applications. In this connection the problem of drives for heat pumps was raised – partly for economic considerations and partly for operational reasons. A comprehensive presentation of the entire "Drives" complex was however not yet endeavoured because, so one believed, too little experience was available. This, however, is not so because in Europe and in the USA all imaginable concepts already exist or are being developed. Apart form the classic electro-drives for compressor installations, at an early stage combustion motors and, in isolated cases, steam drives have established themselves. In addition there are other, non-electric heat pump processes available.–

The conference "Drives for Heat Pumps" will, in continuation of the 'First Essen Heat Pumps Conference 1977' devote itself solely to this subject. It is the intention of the organisers, based on the already discussed fundamentals at the previous conference, exhaustively to discuss the sphere relating to drives for heat pumps as there is not as yet a comparative event or treatise dealing fully with this subject. Many open questions shall be answered founded on the present knowledge of Science and Technology.

It is furthermore the aim of the organisers to concentrate and summarize the world-wide relevant experiences at ONE conference. This also includes, apart from the conventional compressor installations, those which are still rarely seen yet but which do exist and are being developed and tested in Laboratories at this very moment – particularly in the United Kingdom and in the USA. These development trends especially shall be featured at this conference.

The conference takes place at a time when the non-electric heat pumps have just begun to receive their first impetus and at which they have to assert themselves against the conventional electro-drives. That the development in the use of energy shows decisive new applications is only one of many points in question.

Generally the purpose of the 'Second Essen Heat Pump Conference' is, in a broad frame, to do justice to the fundamentals and practical applications of "Drives" in order to show their possibilities and limitations.

The official languages of the conference are German and English. Simultaneous translations can be received by head phones.

Place of Conference:
Haus der Technik, Hollestraße 1, 4300 Essen 1, (opposite Main Railway Station) Phone: (2 01) 18 03–1, Telex: 0 857 669 HDT

Conference Office:
as from 5.9.78, 15.00 hrs. otherwise 8.30–17.00 hrs., Room 2, Haus der Technik, Phone: (201) 18 03–2 73

Information:
University Essen – FB13, Prof. Dr.-Ing. F. Steimle, Dipl.-Ing. J. Paul, Phone: (201) 1 83-26 00/26 03

Organisers:
Haus der Technik e.V., Hollestraße 1, 4300 Essen 1, Phone: (201) 18 03–1, Telex: 0 857 669 HDT

Fees:
DM 270.00 for members of DKV, FGK and HDT (please give membership number), DM 290.00 for non-members.

Booking:
At Haus der Technik giving name, first name, address and name of Company and phone number.

Conference No:
Tagg. T–1–702–10–8–S, Reference: Wärmepumpen

Payment:
into account of Haus der Technik: Postscheckamt Essen 6760–434; Stadtsparkasse Essen 209 007; National-Bank AG Essen 145 009 (Conference number and Reference must be quoted)

Accomodation:
Through: Verkehrsverein Essen e.V., P.O. Box 7042, 4300 Essen 1, Germany. Phone: (2 01) 2 04 21. Conference participants can, on producing entry tickets, book at preferential rates in the Hotel Handelshof. Phone: (201) 22 14 81

Airport:
Düsseldorf Airport (abt. 15 miles from Essen)

TAGUNGSPROGRAMM

6. September 1978

9.00 **Begrüßung**

9.10 Prof. Dr.-Ing. F. Steimle, Universität Essen:
Regelanforderungen an Wärmepumpen und deren Einfluß auf die Auswahl von Antrieben
Leistungsregelung – Temperaturregelung – Wärmequelle/Wärmesenke – Drehzahlverhalten von Wärmepumpenverdichtern – Drehzahlbereiche – adiabater Punkt

9.50 Dr.-Ing. H. Grotstollen, Universität Erlangen:
Möglichkeiten für den elektrischen Antrieb von Wärmepumpen
Elektromotoren; Eigenschaften und Möglichkeiten zur Drehzahlsteuerung – Stromrichtergespeiste Gleichstromantriebe – Stromrichtergespeiste Drehstromantriebe – sonstige drehzahlgesteuerte Drehstromantriebe – Preis/Leistungsverhältnis verschiedener Antriebssysteme – Entwicklungstendenzen

10.30 **Kaffeepause**

10.50 Dr.-Ing. W. Struck, MAN AG – Neue Technologie, München:
Antrieb von Wärmepumpen mittels Dieselmotor
Darstellung der charakteristischen Leistungs- und Betriebsdaten von Dieselmotoren als Antriebe für Wärmepumpen – wärmetechnische und konstruktive Auslegung sowie Regelung von Dieselmotor-Wärmepumpen

11.30 Dr. techn. R. Söllner, Jenbacher Werke AG, Jenbach/Österreich:
Schnellaufende Viertakt-Gasmotoren
Motorbaureihe mit 135 mm Bohrung, 145 mm Hub – Ausführung als Gas-Otto-Motor – Ausführung als Wechselbetriebsmotor – Leistungswerte bei Betrieb mit verschiedenen Gasen – Emissionen – Betriebsverhalten – Regelbereiche – Anwendungsbeispiele – Lebensdauer

12.10 **Mittagspause**

14.00 A.C. Pegley, Ford of Europe, South Ockendon/Großbritannien und A. Rieke, Ford Werke AG, Köln:
Gasmotoren kleinerer Leistung zum Antrieb von Hausheizwärmepumpen
Die Adaption von Großserien-Fahrzeugmotoren für den Betrieb mit gasförmigen Kraftstoffen – Drehzahl- und Leistungsregelung – Standzeiten und Wirtschaftlichkeit

14.40 Dr.-Ing. W. König und Dipl.-Ing. R. Eder, Chemische Werke Hüls AG, Marl:
Dampfantriebe für Wärmepumpen
Vergleich zwischen Wärmepumpenanwendung und Wärme-Kraft-Kopplung – Wärmewirtschaft im Bereich niedriger Temperaturen in Industriebetrieben, Heizkraftwerken und Heizwerken

15.20 **Kaffeepause**

15.40 Dr.-Ing. J. Reichelt, Stiebel Eltron GmbH, Holzminden:
Motorverdichter für Wärmepumpen – mit oder ohne Saugdampfkühlung?
Verwendete Kältemittel – Kondensations- und Verdampfungstemperaturen – Saugdampfüberhitzung – Diskussion der wichtigsten Leistungs- und Betriebsdaten – Schlußfolgerungen

16.20 Dr.-Ing. A.M. Bredesen, Technische Hochschule Trondheim/Norwegen und Dipl.-Ing. J. Paul, Universität Essen:
Einflüsse der Drehzahlregelung auf das Verhalten der Ventile und auf den Wirkungsgrad von Kolbenverdichtern für Wärmepumpen; Ventilverhalten und Ventilverluste
Verhalten von Saug- und Druckventilen – Einfluß der Drehzahl auf die Ventilverluste – Optimierung von Ventilen – Ergebnisse aus Messungen an Kolbenverdichtern

7. September 1978

9.00 Dr.-Ing. W. Malewski, Borsig GmbH, Berlin:
Wärmepumpensystem nach dem Adsorptionsprinzip zur Nutzleistungseinspeisung in Fernwärmeanlagen (Demonstrationsanlage im Rahmen „Fernwärmeschiene Saar")
Optimale Temperaturdifferenzen – Heizenergien – Betriebstechnik – Auslegungsfragen – Wärmequellen – Entwicklungszielsetzungen

9.40 Mng. L.L. Dutram- ju., General Electric Co., King of Prussia/USA und Dir. L.A. Sarkes, American Gas Association, Arlington/USA:
Erdgaswärmepumpen – Bauarten und Neuentwicklungen
Entwicklung alternativer Antriebsarten – Ausführungen von Gaswärmepumpen – Stirling-Maschine – Entwicklung einer Kompressionswärmepumpe mit einem Rankine-Dampfprozeß

10.20 **Kaffeepause**

10.40 B.Sc. D.T.G. Strong, Glynwed Group Services Ltd., Solihull/Großbritannien:
Entwicklung einer direkt befeuerten Wärmepumpe für die Hausheizung
Geschlossener Rankine-Prozeß mit Miniatur-Turboverdichter – Antriebsenergien – Aufbau und Betriebseigenschaften – Betriebsmittel – Erfahrungen mit dem Prototyp – Primärenergienutzungsgrad

11.20 Techn. Leiter G. Bauer, AWAK Apparatebau-Wärmepumpen, Coburg:
Kleine Gas- und Dieselmotor-Wärmepumpen
Vor- und Nachteile der Gas- und Dieselmotor-Wärmepumpe gegenüber der Elektrowärmepumpe – bivalenter und monovalenter Betrieb mit Gas- und Dieselmotor-Wärmepumpen

12.00 Prof. Dr.-Ing. Th. Rummel, Technische Universität Hannover:
Wärmepumpen mit Dieselmotorantrieb und mit kombiniertem Dieselmotor-Elektromotor-Antrieb
Antrieb und Wirkungsweise – Anlassen und Abstellen – Antriebs- und Kupplungssysteme – Steuerung bzw. Regelung – erreichte Primärenergieeinsparung – ausgeführte Anlagen

12.40 **Mittagspause**

14.00 Ing. J.P. Winkler, Soltron Ing.-Büro für Wärme- und Klimatechnik, Bern/Schweiz und Ing. P. Schneider, Brügg/Schweiz:
Wärmekraftkopplungsanlagen – Kriterien der Dimensionierung
Heizlast – Kühllast – Stromerzeugung – Erfahrungen mit der Dieselwärmepumpe bis 100 kW – Erfahrungen mit der Dieselwärmepumpe bis 1000 kW – Anforderungen an die Meß- und Regeltechnik der Steuerelektronik für Wärmekraftkopplungsanlagen – Praktische Erfahrungen

14.40 Dipl.-Ing. L. van Heyden, Ruhrgas AG Essen/Dorsten:
Übersicht der in der Bundesrepublik Deutschland projektierten Gaswärmepumpen-Anlagen
Auslegung – Wärmequellen – verwendete Aggregate

15.20 **Kaffeepause**

15.40 Dipl.-Ing. U. Fox, Ing.-Büro für Haustechnik Dr.-Ing. F. Broer, Paderborn und Fachhochschule Münster:
Auslegung einer Großwärmepumpenanlage unter Berücksichtigung verschiedener Antriebsenergien
Das Projekt 'Großwärmepumpe Paderborn' – Auslegungsdaten – technischer Aufbau – alternative Antriebsenergien durch Elektro- und Dieselmotoren – Investitions-, Betriebs- und Wärmekosten im Vergleich zueinander

16.20 Dipl.-Ing. D. Herbst, Dr. Walter Herbst Ing.-Ges. mbH, Berlin:
Wärmepumpe mit Gasmotor für Heizung und Kühlung eines Kaufhauses
Anlagenschema – Wirtschaftlichkeit – Betriebsdaten als Kälteerzeuger – Betriebsdaten als Wärmeerzeuger – Regelung der Leistung – Betriebserfahrungen

17.00 **Schluß der Tagung**

Appendix B

Natural Gas Heat Pump Specifications

1. AWAK Heat Pump Specifications
2. Floridan-Bauer Heat Pump Specifications

Luft - Wasser WP mit Gas-Motor

Type	Kompr. Type	Drehzahl ($^1/min$) Motor	Drehzahl ($^1/min$) Kompr.	Antriebsleistung (kW)	Kälteleistung (R12) Verdampfer (kcal/h)	Kälteleistung (R12) Verdampfer (kW)	Kälteleistung (R12) Kondensator (kW)	Motor Abwärme Kühlwasser (kW)	Motor Abwärme Abgas (kW)	Brennstoffverbrauch * (m^3/h)		COP
GLW 30	F 4	1500	1500	4	12 000	14	18	6	6	2,9	25.8 kw	1.16
GLW 46	F 5	1500	1500	7	20 000	23	30	8	8	3,5	31.1 kw	1.48
GLW 58	F 5	1800	1800	9	25 000	29	38	10	10	4,5	40.0 kw	1.45
GLW 70	Fk 5	2200	2200	11	31 000	36	47	11	12	5,9	52.5 kw	1.33
GLW 87	F 6	2200	1450	15	34 000	40	55	13	19	6,8	60.5 kw	1.44

Auslegungsdaten: $t_o = -5^oC$ / $t_k = +50^oC$

* nach Angaben des Motorherstellers bei $H_u = 7650\ kcal/m^3$

Wasser - Wasser WP mit Gas-Motor

Type	Kompr. Type	Drehzahl Motor	Drehzahl Kompr.	Antriebsleistung (kW)	Verdampfer (kcal/h)	Verdampfer (kW)	Kondensator (kW)	Kühlwasser (kW)	Abgas (kW)	Brennstoffverbrauch * (m^3/h)	
GWW 35	F 4	1500	1500	4	16 000	19	23	6	6	2,9	1.36
GWW 55	F 5	1500	1500	8	23 000	27	35	10	10	4,0	
GWW 68	F 5	1800	1800	10	30 000	35	45	11	12	5,0	
GWW 85	Fk 5	2200	2200	12	38 000	44	56	12	17	6,4	
GWW 103	F 6	2200	1450	15	48 000	56	71	13	19	6,8	

Auslegungsdaten: $t_o = 0^oC$ / $t_k = 50^oC$

* nach Angaben des Motorherstellers bei $H_u = 7650\ kcal/m^3$

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Florian Bauer
MASCHINEN- UND APPARATEBAU

5030 HÜRTH-HERMÜLHEIM
Luxemburger Straße 277
Telefon Hürth (02233) * 75051
Telex pope d 889 338

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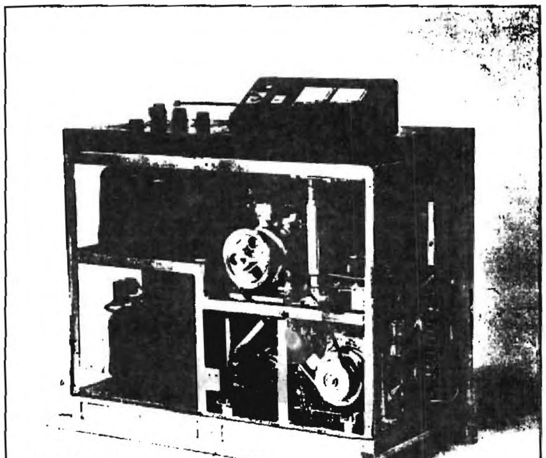
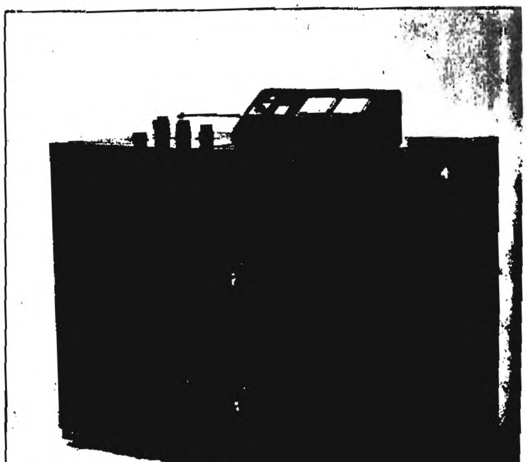
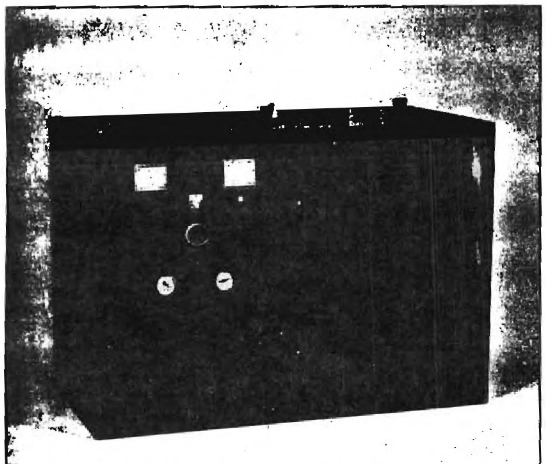


Gasmotor-Wärmepumpe
in Wasser / Wasser
und Luft / Wasser-Bauweise.
Leistung von 9 KW – 400 KW · Warmwassertemperatur bis +70°/+90° C.



Dieselmotor-
Wärmepumpe in Wasser / Wasser
und Luft / Wasser-Bauweise.
Leistung von 8 KW – 550 KW · Warmwassertemperatur bis +70°



Elektromotor-Wärmepumpe in Wasser / Wasser-Bauweise.
Leistung von 2 KW – 2000 KW.
Warmwassertemperatur bis + 55° C.

Elektromotor-
Wärmepumpe
in Luft / Wasser-
Bauweise.
Leistung
von 2 KW – 106 KW
in Split-Ausführung
bis 2000 KW.

Absender: ____________

____

____

____

O Gas-Motor-Wärmepumpen
Wasser/Wasser Luft/Wasser
O Diesel-Motor-Wärmepumpen
Wasser/Wasser Luft/Wasser
O Elektro-Motor-Wärmepumpen
Wasser/Wasser Luft/Wasser
O Brauchwarmwasser-Wärmepumpen mit Speicher
O Schwimmbadentfeuchtung mit Wärmerückgewinnung

Antwortkarte

Bitte freimachen

AWAK-Wärmepumpen
Postfach 674

8630 Coburg

AWAK-GmbH
Apparate-Wärmepumpen-Anlagen-Kälte
Postfach 674
Telefon 0 95 61 / 13 41

Unser Vertiebspartner ist:

Gasmotor-Wärmepumpe
Wasser-Wasser

AWAK GmbH

Der Einsatzbereich der Gas- und Dieselmotor-Wärmepumpen liegt ähnlich wie bei den Elektromotor-Wärmepumpen. Der große Vorteil der Gas- und Dieselmotor-Wärmepumpen gegenüber den Elektromotor- Wärmepumpen liegt darin, daß die Wasservorlauf-Temperaturen wesentlich höher sein können.
Statt ca. +55°C liegen sie je nach An - wendung und Einstellung bis zu +95°C.
Diese Temperaturen erreichen wir dadurch, daß wir zusätzlich zur Wärmepumpenwärme von max. +55°C/+65°C die Motorwärme und Abgaswärme von max. +95°C zur Verfügung haben.

Durch die getrennten Wärmetauscher können die Temperaturen gemischt werden, sodaß eine Vorlauftemperatur von max. +75°C erreicht wird, oder man nimmt die Motor- und Abgaswärme zur Brauchwarmwasser-Bereitung vorranig und heizt danach den Heizungsvorlauf nach.

Die Abgase liegen in dem Bereich der gültigen Emmissionsschutzgesetze.
Der weit größere Vorteil der Gas- und Dieselmotor-Wärmepumpen liegt jedoch in der noch größeren Energieeinsparung von bis zu 60 %.

Technische Daten A W A K - Wärmepumpen Wasser / Wasser Gasmotor

	Modell AWWP	(1) Ges.Nennheiz-leist.b.+45°C KW/kcal/h	(2) Ges.Heiz-leist.b.+70°C KW/kcal/h	(3) Heizleist. 80°C KW/kcal/h	(4) Heizleist. 45°C KW/kcal/h	Gas-verbr. KW/h	Drehz. U/min	Warm-wasser m³/h	Druck-abfall bar	Kalt-wasser m³/h	Druck-abfall bar	Maße l/b/h	Gew. kg
Wi	8 G	9,7/ 8400	9,5/ 8200	4,3/ 3700	5,4/ 4700	7,4	1800	0,9	0,08	0,8	0,15	1400/ 750/1180	165
Wi	10 G	12,2/ 10500	11,9/ 10300	5,2/ 4500	6,9/ 6000	8,9	1500	1,1	0,08	1,1	0,15	1400/ 750/1180	174
Wi	13 G	15,8/ 13600	15,4/ 13300	6,9/ 6000	8,8/ 7600	11,7	1500	1,3	0,09	1,3	0,15	1400/ 750/1180	196
Wi	18 G	21,7/ 18700	21,1/ 18200	8,7/ 7500	13,0/11200	14,7	1500	1,8	0,1	1,9	0,2	1400/ 750/1180	235
Fo	25 G	31,1/ 26800	30,5/ 26300	13,7/ 11800	17,4/15000	23,0	1500	2,5	0,2	2,6	0,2	1400/ 750/1180	261
Fo	28 G	34,6/ 29800	33,9/ 29200	14,8/ 12800	19,4/17000	25,0	1500	2,9	0,2	3,0	0,2	1600/ 750/1400	460
Fo	38 G	47,4/ 40800	46,5/ 40000	19,5/ 16800	27,9/24000	32,7	2000	3,5	0,2	4,0	0,35	1600/ 750/1400	490
F/Wa	58 G	71,1/ 61200	70,3/ 60500	29,7/ 25600	41,4/35600	50,0	1600	5,8	0,3	6,2	0,3	1600/ 750/1400	510
Wa	70 G	88,3/ 76000	87,4/ 75200	37,2/ 32000	51,1/44000	62,5	1500	7	0,3	7,5	0,7	1600/ 750/1400	590
Wa	87 G	105,8/ 91000	103,3/ 88900	43,0/ 37000	62,8/54000	72,5	1500	9	0,3	9,5	0,6	2000/1000/1600	615
Wa	114 G	143,0/123000	138,3/119000	61,6/ 53000	81,4/70000	104,0	1500	12	0,3	12	0,5	2000/1000/1600	640
Wa	140 G	173,2/149000	169,7/146000	70,9/ 61000	102,3/88000	118,9	1800	13	0,25	15	0,5	2000/1000/1600	710
Wa	174 G	215,1/185000	209,3/180000	81,4/ 77000	125,6/108000	146,5	1500	17	0,3	18	0,6	2000/1000/1600	760
Wa	227 G	282,1/242600	274,4/236000	119,3/102600	162,8/140000	195,3	1500	21	0,25	24	0,5	2500/1300/1800	1180
Wa	330 G	397,3/341700	386,1/332000	164,7/141700	232,6/200000	288,4	1500	32	0,35	36	0,5	2500/1300/1800	1320

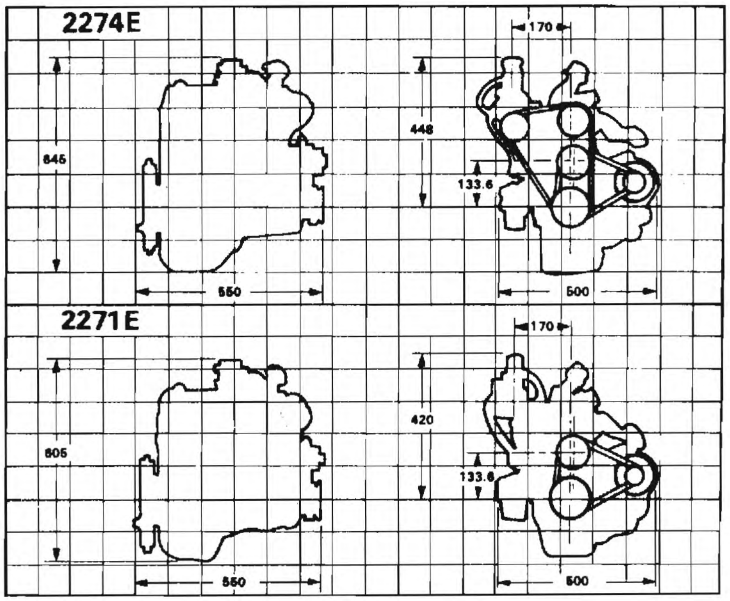
(1) Gesamtheizleistung bei Kältemittel R22 maximale Temperatur + 70°C
(2) Gesamtheizleistung bei Kältemittel R12 maximale Temperatur + 75°C
(3) Diese Heizleistung bezieht sich auf die reine Gasmotorabwärme einschl. Abgaswärme maximale Temperatur + 90°C
(4) Diese Heizleistung bezieht sich auf die reine Wärmepumpenleistung ohne Gasmotorwärme maximale Temperatur + 65°C R 12

Features

- Small package size.
- Low weight.
- Low noise level.
- Low fuel consumption.
- Worldwide service availability via automotive outlets.
- Heavy duty crankshaft thrust washers.
- Provision for constant and variable speed governors.
- Provision for solid state ignition equipment.
- Provision for axial power take-off.
- Provision for 70 Nm (51lbf ft) axial torque from the front of the crankshaft.
- Induction hardened exhaust valve seats on dry fuel engines.†
- Heavy duty stellite faced exhaust valves and valve rotators on gasoline engine.†
- Available as a low line engine package.
- Wide range of industrial options.

† available for 2274E engine only

Dimensions



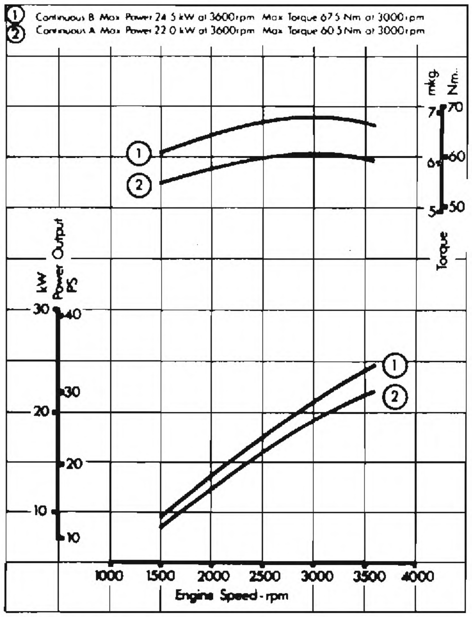
Specification

Model No.	2274 E	2271 E
Engine Type:	4 cylinders in line	4 cylinders in line
Combustion System:	Crossflow, four stroke	Crossflow, four stroke
Bore:	80,98 mm	80,98 mm
Stroke:	77,62 mm	53,29 mm
Displacement:	1599 cc	1098 cc
Compression Ratio:	8,0:1 (Gasoline and LPG) 9,0:1 (Natural Gas)	8,0:1
Cooling System:	Belt-driven impeller type pump	Belt-driven impeller type pump
Water Pump Delivery:	82 litres/min. at 3600 rpm	82 litres/min. at 3600 rpm
Engine Oil Capacity:	4,0 litres	3,6 litres
Oil Pan Type:	Pressed steel-rear well	Pressed steel-rear well
Heat to Coolant:	25 kW at 3600 rpm	16 kW at 3600 rpm
Carburettor:	Single venturi/manual choke	Single venturi/manual choke
Thread Types:	Metric and Unified National	Metric and Unified National
Weight:	120 kg (This weight is approximate as it depends on the engine build specified.)	110 kg (This weight is approximate as it depends on the engine build specified.)

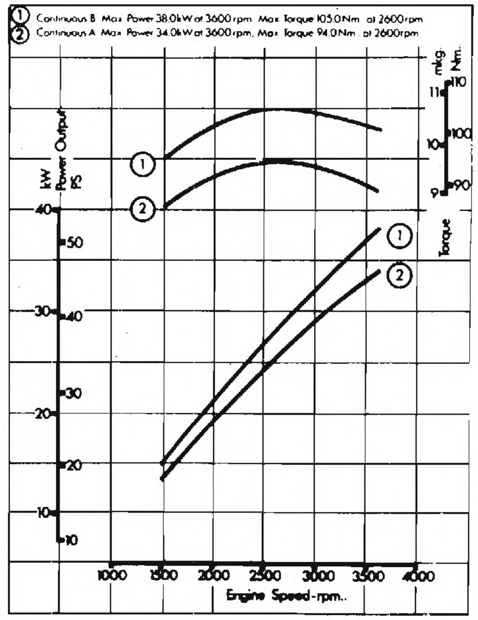
Optional Equipment

- High level fan kit.
- Water pump fan spacer.
- Various crankshaft pulley arrangements including axial power take-off.
- SAE 5 flywheel housing.
- Two types of flywheel.
- Two types of air cleaners.
- Range of pusher and puller fans.
- Air velocity overspeed control governor.
- Updraft intake manifold.
- Universal side outlet exhaust manifold.
- Reduced height rocker cover.
- Lifting eyes.
- Liquid Petroleum Gas conversion equipment.
- Natural gas conversion equipment.
- LPG/Gasoline dual fuel equipment
- Electronic breakerless solid-state

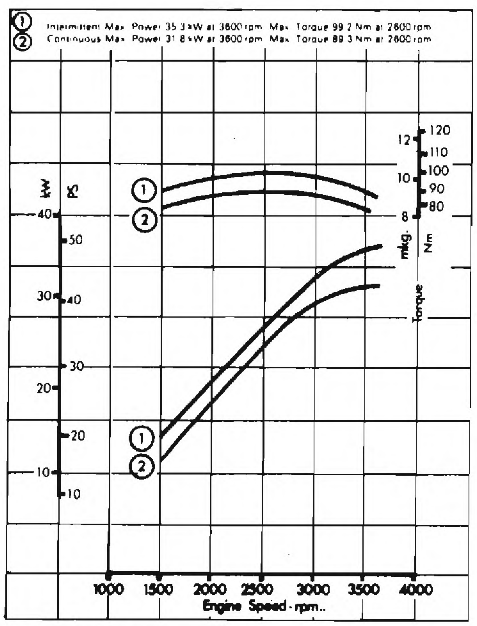
All base engines include heavy duty crankshaft thrust washers, carburettor*, inlet and exhaust manifolds, fully closed crankcase emission, rear well oil pan, oil pump, oil filter, oil pressure switch, oil level indicator, flywheel, clutch pilot bearing, water pump, single sheave pulley, fuel pump*, distributor and wiring assembly, sparking plugs, thermostat, water outlet connection and



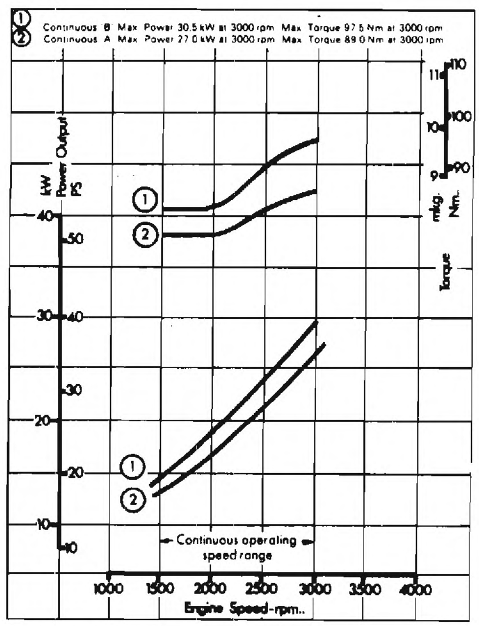
2271E.(LC.)Gasoline



2274E.(LC.)Gasoline



2274E.(LC.)Typical LPG



2274E.(HC.)Typical Natural Gas

Appendix C

Gas and Electric Rate Schedules

All fuel oil costs were computed at the rate of \$0.40/gallon.

Purchased gas adjustment to natural gas rates was made at the September, 1978 rate of \$0.1348/therm.

Fuel adjustment to electrical rates was made at the average 1978 rate of \$0.003352/kwh.

Sixth Revised **Sheet No.** 9

Canceling Fifth Revised **Sheet No.** 9

ATLANTA GAS LIGHT COMPANY

RATE N-1

RESIDENTIAL GAS SERVICE

Territory:
In the certificated natural gas areas of the Company as shown on the current Rate Zone Map on file with the Georgia Public Service Commission. This schedule does not apply to any territory for which there is another Residential Service Rate Schedule applicable and on file with the Georgia Public Service Commission.

Available:
To any regular natural gas customer using gas for residential purposes in the territory shown above.

Rate:

Therms	Net
For the first 4.0 or less used per month	$2.25
	Per Therm
For the next 11.0 used per month	14.3¢
For the next 285.0 used per month	9.7¢
For all over 300.0 used per month	7.4¢

Gas used for space heating only shall not average less than 13.0¢ per Therm.

Minimum Monthly Bill:
The minimum monthly bill shall be $2.25

Summer Air-Conditioning Rate:
To any residential customer who has installed and regularly operates a gas-fired central air-conditioning system which meets Company's specifications. All provisions of the above rate schedule will apply except as specifically modified herein.

All gas used in excess of 50 Therms per month during the period between the customer's meter reading occurring between May 1 and May 31, inclusive, to the customer's meter reading occurring between September 1 and September 30, inclusive, will be billed at 7.4¢ per therm.

Payment:
Bills are due when rendered at the net rate shown above and shall be paid in full at any office of the Company within ten (10) days from

Effective: With Service on and after December 9, 1976

Fifth Revised **Sheet No.** 10

Canceling Fourth Revised **Sheet No.** 10

ATLANTA GAS LIGHT COMPANY

RATE N-1

RESIDENTIAL GAS SERVICE

Payment (Cont'd):
the date mailed or otherwise delivered.

Multiple Billing:
When the Company serves two but not more than four housekeeping apartments in a single building for residential purposes or a number of separate dwelling houses under common ownership on the same premises, with service through a single meter installation, the minimum charge and the quantity of gas within each block of the above rate shall be multiplied by the number of individual dwelling units.

Terms of Service:
Service on this rate is subject to the Terms of Service for General Service Rates, Sheet Nos. 7, 8 and 8-A, and the Rules and Regulations of the Company as filed with the Georgia Public Service Commission.

Purchased Gas Adjustment Provision:
This rate is subject to being increased or decreased in accordance with the "Purchased Gas Adjustment Rider" ordered by the Georgia Public Service Commission, Docket No. 2145-U, February 19, 1970 effective with meter readings on and after March 15, 1970.

Effective: With billings on and after

January 15, 1973

GEORGIA POWER COMPANY

Residential Service

SCHEDULE "R-4"

AVAILABILITY:

Throughout the Company's Service Area from existing lines of adequate capacity.

APPLICABILITY:

For all domestic uses of a Residential Customer in a separately metered single family dwelling unit. A Residential Customer hereunder is defined in Rules and Regulations for Electric Service.

TYPE OF SERVICE:

Single or three phase, 60 hertz, at a standard voltage.

MONTHLY RATE:

WINTER — October through May

Base Charge	@	**$2.75**	
First 650 kWh	@	**2.9¢**	**per kWh**
Over 650 kWh	@	**3.19¢**	**per kWh**

SUMMER—June through September

Base Charge	@	**$2.75**	
First 650 kWh	@	**2.9¢**	**per kWh**
Over 650 kWh	@	**4.39¢**	**per kWh**

Minimum Monthly Bill: $2.75

FUEL ADJUSTMENT:

The amount calculated at the above rate is subject to increase or decrease under the provisions of the Company's Fuel Adjustment Rider, Schedule "FA-2".

BUDGET BILLING OPTION:

When a Customer's annual billing exceeds $300, the Customer may be offered the option of being rendered a budget bill which has the effect of leveling the Customer's monthly billing amount. Details of this billing option are on file in each Company office and with the Georgia Public Service Commission.

MULTIPLE SERVICE:

Where two or more dwelling units are served through a single meter, each kWh block in the above monthly rate shall be multiplied by the number of separate dwelling units so served.

The minimum monthly bill under this option shall be $2.75 times the number of dwelling units served. Billing under this provision shall be designated "R-4-M".

TERM OF CONTRACT:

One year.

Service hereunder subject to Rules and Regulations for Electric Service on file with the Georgia Public Service Commission.

Effective for service rendered on and after September 18, 1977